Overcoming Difficulties in Computing Flow-Frequency in the Truckee Meadows Reach, Truckee River, Nevada

by John High[1]

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Abstract: Many difficulties arose in deriving the existing conditions hydrology needed to create floodplains and analyze alternatives for flood reduction for the Truckee Meadows reach on the Truckee River, Nevada. In order to perform the analysis, a unique methodology had to be derived for this reach. This paper shows methods that can be used to develop flow-frequency for an area where typical Bulletin 17B Methods are not adequate.

Introduction: The Truckee River begins at the outlet of Lake Tahoe in California and flows down the steep, eastern slope of the Sierra Mountains before passing through the desert valley floor and the cities of Reno and Sparks City, Nevada. Excluding Lake Tahoe, which rarely contributes flow during floods, the total drainage area for the streamgage at Reno is 561 mi^2. Four federal dams on tributaries to the Truckee (with designated flood space) control 25% of this area. Chart 1 shows the watershed. The overwhelming percentage of storm-induced runoff that threatens Reno and Sparks City, Nevada, comes from the 420 mi^2 of uncontrolled watershed below the dams and above the Reno streamgage. Downstream of the Reno gage and the downtown area lies several miles of a low-lying, broad, floodplain called the Truckee Meadows. Downstream of the meadows and upstream of the Vista gage, the channel passes through a narrow, constricted, v-shaped canyon called the Vista Reefs. The reefs induce backwater during floods that creates a large lake in the meadows. Chart 2 shows the Truckee Meadows 1% chance exceedence floodplain upstream of the reefs.

The flood of record occurred on January 2nd, 1997, when an extremely warm, moist pacific storm crossed over the Sierra Mountains melting much of the snowpack below 7,000 feet. The combined snowmelt and rainfall-induced runoff created a peak flow estimated at 23,000 cfs to pass through Reno City. In Reno, levees built close to either side of the river were designed to contain 14,000 cfs (approximately a 2% chance exceedence event). The flow overtopped the levees and flooded portions of downtown near the river. Farther downstream in the Truckee Meadows reach, where a more loose knit system of levees can contain only 6,000 - 8,000 cfs, large amounts of overbank storage flooded the city airport, industrial warehouses, and homes. Estimated damages for this event, which is believed to have a return period of about 120 years at the Reno gage, were over a half a billion dollars. This flood is believed to be the largest since 1869.

Challenges in the Truckee Meadows: Deriving floodplain depths in the Truckee Meadows with a hydraulic model is complicated by backwater effects from the downstream Vista Reefs, contributing flows from numerous local creeks in the meadows, and a complex movement of water within and between the main channel and the meadows' numerous storage areas. In 2001, the Corps of Engineers built a new Unsteady Flow HEC-RAS model of this reach. The model uses weirs to hydraulically connect the main channel and overbank storage areas to each other.

The unsteady hydraulic model requires a mainstem hydrograph for the upstream index point and tributary hydrographs with a set timing to represent the local runoff. Approximately 280 mi^2 of mountain, foothill, and valley drainage contributes flow to the Truckee River in the 5-mile reach between the Reno and the Vista streamgages. These tributaries are mostly ungaged and the relative timing of their peak runoff during floods on the Truckee is not well documented. The timing of the runoff from the tributaries in relation to that of the mainstem will influence the floodplain depth. During a flood that exceeds channel capacity, backwater and overbank storage can reduce the peak 1-day maxima at the Vista gage below that recorded at the Reno gage. This makes quantifying the coincident flow contribution from the local creeks difficult.

In 2001, during a Corps of Engineer analysis of the existing condition floodplain depths, a plan was developed to deal with the uncertainties of modeling this reach.

Methodology: Dr. Dave Goldman, hydrologist and statistician at HEC, Gary Brunner, hydraulic engineer at HEC, Bob Collins, Senior hydrologist at the Sacramento District of the Corps of Engineers, the author, and others worked on ideas to properly model the floodplain depths in the Truckee Meadows.

The plan that developed centered on developing a peak flow frequency curve at Vista from historic data. The peak flow that is recorded at Vista is directly related to the depth of water passing through the Vista Reefs (performs like a weir). The reefs are connected by backwater to the meadows. By attaining a "target peak flow" at Vista in a hydraulic model, the proper flood depth in the Truckee Meadows reach is achieved. To achieve the target, only the size of the tributary hydrographs and their timing would be adjusted in the hydraulic model. These inputs were considered to have the greatest uncertainty. The timing of tributary runoff for the first run was set to the average of the three events for which this was known (floods of 1963, 1986, and 1997). Any adjustment to the timing was made within a reasonable range based on these historic events.

The period of record at the Vista gage is non-homogenous due to many factors: a) channel improvements completed in 1963 just upstream of the gage, b) the record of annual peak flows includes a mixture of rainflood and snowmelt events, and c) the construction of reservoirs (the last being completed in 1972). With so few homogenous data points, construction of a graphical, existing-condition frequency curve at Vista is difficult.

Methods to Estimate Peak Flow Frequency at Vista: Two methods suggested by Dr. Goldman were used to determine the target peak flows at Vista for 1% chance exceedence or more frequent events. The existing condition flow frequency curve derived for the Reno gage was considered sound. It was based on an unregulated flow frequency curve with 78 years of record. The two methods described below are based on an assumption of dependence between the Reno and Vista gages.

Method 1: In the first method, the coincident peak flows for Reno and Vista were used to plot points on a graph. The x-axis was used for the Reno peak and the y-axis for the Vista peak. Only rainflood events that occurred after the 1963 improvements to the channel above the Vista gage were analyzed. Snowmelt peaks are considered a distinct phenomenon or population. A curve was developed from the plotted points to derive a relationship between the Reno and Vista peaks. Using the known 1% chance exceedence peak flow at Reno, a corresponding 1% chance event at Vista could be estimated.

Chart 3 shows two curves drawn for this purpose. One is derived by a regression equation (best-fit line) and the other is a smooth curve connecting the points. The decision as to how to draw the curve is up to the judgment of the hydrologist or engineer. Several factors determine the peak at Vista during an event. These include the attenuation and loss of water in the Truckee Meadows reach, the amount and timing of the local tributary runoff, and the restricted channel capacity through the narrow Vista Reefs. The arching bow in the hand-drawn curve on Chart 3 is driven by the 1963 and 1986 events, in which it is known that the percent contribution of runoff from the tributaries was high. Table 1 shows the local flow contribution for four floods based on the difference in peak 7-day values at the two gages.

Table 1. Local Flow Contribution: Increase in Peak 7-Day Volume from Reno to Vista

Water Year of Flood	Percent Increase in 7-Day Volume (Reno to Vista)
1963	**21**
1964	13
1986	**33**
1997[1]	11

[1] 1997 flood is believed to have been the largest since 1869, with an estimated peak of 23,000 cfs at Reno and 21,300 cfs at Vista based on calibration of an HEC-RAS Unsteady Flow Model to high-water marks by the Corps of Engineers. USGS published peak flows are lower.

It could be inferred from the above table that the amount of tributary runoff may have a major influence on the shape of the curve within this range of flows. Since the amount and timing of the local flow is variable from one event to the other, a best-fit line (regression) might give the best mean estimate of the relationship between the Reno and Vista peaks.

Method 2: As in Method 1, Method 2 for peak flow prediction at Vista used only post-1962 rainflood data. For each water year, the frequency of the observed peak flow at the Reno gage was determined using the existing conditions frequency curve. The corresponding Vista gage peak for the same storm was assigned the exact same frequency. The observed Vista flows and their "assigned frequency" were plotted on frequency paper. The points were used to determine the shape of a Vista frequency curve. See Chart 4. This method of analysis assumes that the Reno and Vista gages incur a similar frequency of flow during each flood. This is not necessarily true but nevertheless a useful assumption for this analysis.

The two methodologies resulted in fairly similar estimates of peak flow as shown on Table 2 below. It should be pointed out that the two methods described above were only used to estimate the 20% through 1% chance exceedence values. For more rare events, the dual effects of overbank storage in the meadows and backwater caused by the Vista Reefs were determined to be too complicated to estimate without historical data in that range. Chart 5 shows the divergence of the two methods (frequency curves) for rare events. The peak flow for the 0.5% and 0.2% chance exceedence events was determined by a method used in a 1999 study, inputting design hydrographs into an unsteady flow hydraulic model, with a set timing, and letting the model determine the peak flow at Vista.

Table 2. Target Peak Flow Estimates for Truckee River at Vista, Comparison of Methods

Frequency of Event in Percent Chance Exceedence	Range of Estimates Derived by 2 Methods Used to Determine Target Flow (cfs)
20% chance flow	6000 – 6600
10% chance flow	7900 – 8200
5% chance flow	9500 – 10900
2% chance flow	14,100 – 14,600
1% chance flow	20,000 –20,200

Tributary Hydrograph Volume: The two parameters that were adjusted to meet the target peak flow at Vista for each frequency modeled were the size of the local tributary hydrographs (total volume) and their timing. To modify volume, all tributary pattern hydrographs were increased or decreased by a single ratio, and put back into the hydraulic model. An independent estimate of the tributary volume was needed for three main reasons: 1) to size the tributary pattern hydrographs for the initial hydraulic model run 2) to verify the reasonableness of the tributary volume needed to attain the target peak and 3) to calculate the hydrograph volume to be used in the 0.5% and 0.2% chance exceedence events (no target peak).

Tributary volume was estimated by subtracting the 7-day unregulated frequency curves at Vista and Reno. Shorter durations like the 1- and 3-day curves could not be used since it takes more than 3 days for the floodwater in the meadows to drain back into the Truckee River and reach the Vista gage. The Reno and Vista frequency curves computed using a Log Pearson III Distribution crossed each other above the 0.2% chance exceedence.

Subtracting values on the two curves for the 0.5% and 0.2% chance exceedence resulted in volumes that were smaller than the calculation for the 1% chance event. It was recognized that the proper trend should be an increasing amount of runoff from the tributaries for more rare events. The two curves are shown on Chart 6.

Regionalizing the flow frequency statistics at various gages on the Truckee River has been found to be difficult. The plotted historic data does not form a smooth curve. The peaks near the 50% chance exceedence start to increase sharply upward. This phenomenon is found at every mainstem gage on the Truckee River. The reason is not known. One theory proposed by Bob Collins (District Hydrologist at the Corps' Sacramento District) is that the Truckee watershed has many meadows and depressions that inhibit runoff. The threshold at which this depression storage becomes saturated or filled is where the data starts to curve upward at a steeper angle. In the late part of the 1990's, the Corps attempted to use distributions other than Log Pearson Type III for the Truckee River gages but did not find this helpful. The computed skew on the Truckee River gages can be quite high. It is believed that the tendency of the plotted data to start curving sharply upward near the 50% exceedence plays a role in the positive skew computation. The fit at the upper end of the curve to the plotted data is less than desirable.

It is believed that the shapes of the curves on Chart 6 are more reasonable for the middle portion of the curve. It is the upper tail of the curves that results in problems. Two methods to re-analyze the curves are described below (methods suggested by Dr. Goldman).

Method 1: The water years from which the two curves were developed are different. The Reno record starts in 1907 and contains 83 years of record, while the Vista gage starts in 1899 and has 78 years of record. Gaps exist in both. To build two new curves, only water years that are common to both gages were analyzed. Upon calculating new statistics on the data sets, the two curves still crossed. The two data sets were further modified so that each contained the **exact same storms**. The 7-day period that caused the highest average flow at Reno was used to find the corresponding 7-day average at Vista. Two new curves were created from this specialized data set. They are displayed on Chart 7. A zero skew was adopted which seemed to better represent the upper end of the frequency curve. Subtracting values on the two curves derived new estimates of volume.

Method 2: Using the two data sets of overlapping storm events developed above, the observed 7-day value at Reno was subtracted from the corresponding 7-day value at Vista. The resulting differences "Z_n" were then analyzed using Bulletin 17B methods to produce a new frequency curve. Table 3 illustrates this method.

Table 3: Illustration of Method 2

Storm Event	Vista Peak 7-Day Average Flow	Reno Peak 7-Day Average Flow	$Y_n - X_n = Z_n$ (Tributary 7-Day Flow)
Feb 1962	Y_1	X_1	Z_1
Jan 1963	Y_2	X_2	Z_2
Dec 1964	Y_3	X_3	Z_3
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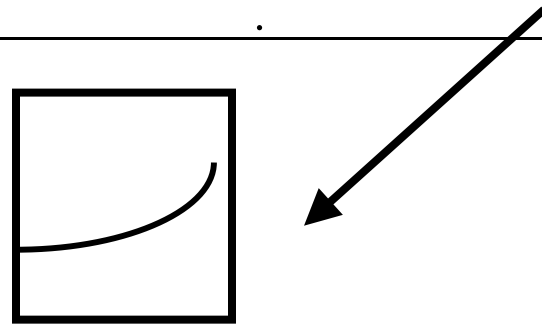


Frequency curve derived from statistical analysis of values of Z_n

Method 1 seemed to give the most reasonable answers and was adopted. Table 4 shows the results of method 1 as compared with the results found by subtracting the two crossing curves on Chart 6.

Table 4: Comparison of Tributary Volume Calculated from

Frequency of Event in Percent Chance Exceedence	7-Day Volume Derived from Curves on Chart 6 (cfs-days)	7-Day Volume from Curves on Chart 7 (cfs-days) [1]
5%	1060	890
2%	1400	1360
1%	1420	1870
0.5%	1310	2540
0.2%	493	3795

[1] Values calculated in this column were used to derive the initial 7-day volume of the tributary hydrographs for input into the hydraulic model. For the 0.5% and 0.2% chance exceedence events, no adjustment was made to the tributary hydrographs after the first run since no target peak was used.

Hydraulic Modeling Results: The hydraulic model was run to attain the target peak flows. Table 5 gives a comparison of the volumes needed to attain these targets versus the estimated volumes from Method 1 above.

Table 5: Truckee Meadows Tributaries 7-Day Volume

Percent Chance Exceedence	Estimated 7-Day Tributary Volume (cfs-days)	7-Day Tributary Volume Required to Attain Target Peak Flow (cfs-days)
5%	890	650
2%	1320	1400
1%	1870	2310

Table 5 shows a reasonable proximity between the estimated volumes and those required to meet the target peaks in the hydraulic model. Therefore, it was concluded that the volumes calculated in Table 4 were reasonable for use in modeling the 0.5% and 0.2% chance exceedence events. Since the flow dynamics caused by overbank storage in the meadows and backwater at the Vista Reefs are too complex to predict without having historic flows of this magnitude, no target peak flow was used for these frequencies. The peak flow for these rare events was determined by a method used in a 1999 study, inputting design hydrographs into an unsteady flow hydraulic model, with a set timing, and letting the model determine the peak flow at Vista. The two methods for estimating Vista peak flow frequency were compared with the hydraulic model output. Table 6 shows the comparison.

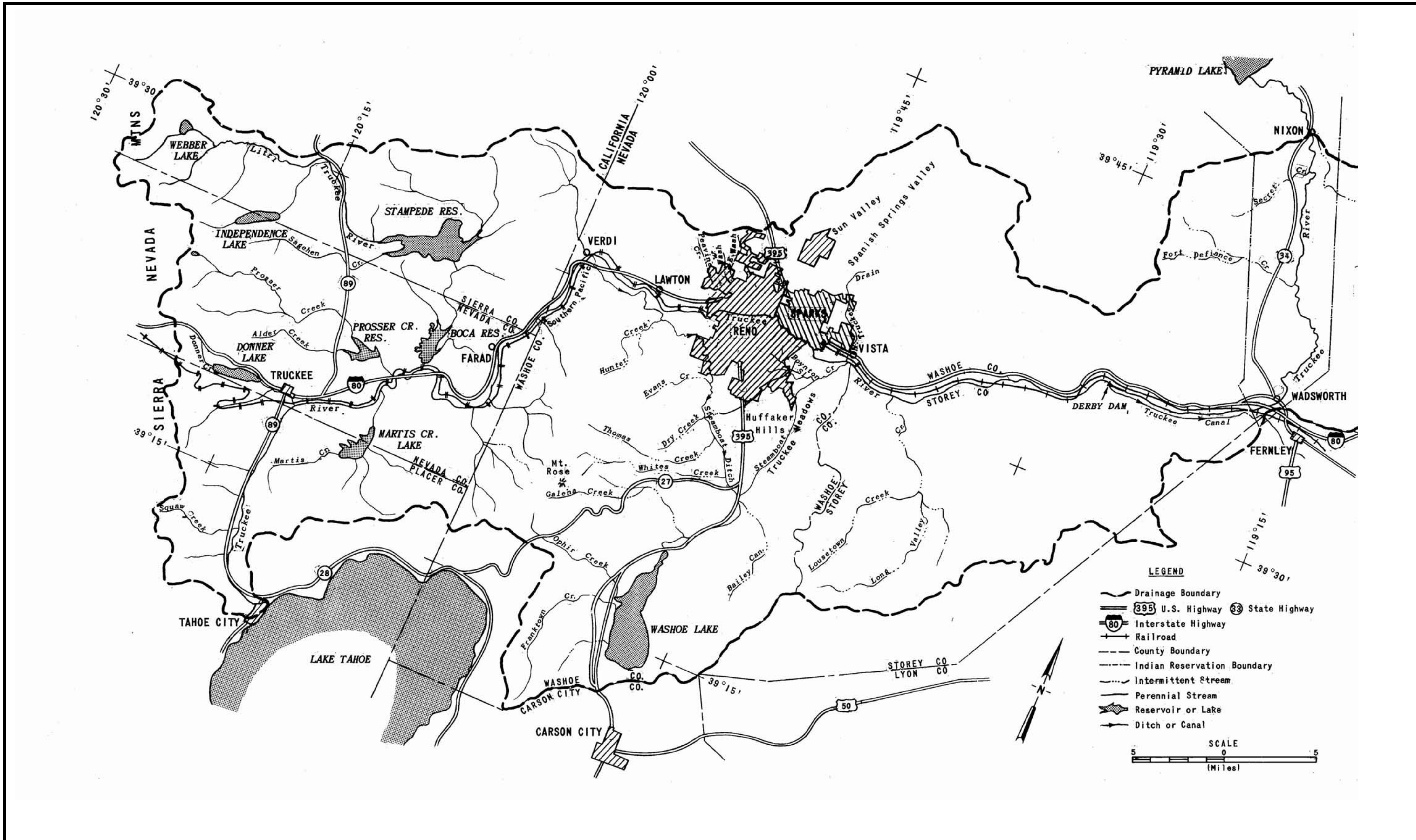
Table 6: 0.2% and 0.5% Hydraulic Model Peak Versus Estimates

Percent Chance Exceedence	Peak Flow From Hydraulic Model	Method 1 Estimate (cfs)	Method 2 Estimate (cfs)
0.5%	**29,300**	32,000	27,500
0.2%	**52,000**	54,000	40,000

Both Method 1 and 2 for estimating Vista peak flow frequency gave reasonable estimates for the 0.5% chance exceedence event. The two methods diverged siginificantly for the 0.2% chance event, with Method 1 coming extremely close to the hydraulic model results.

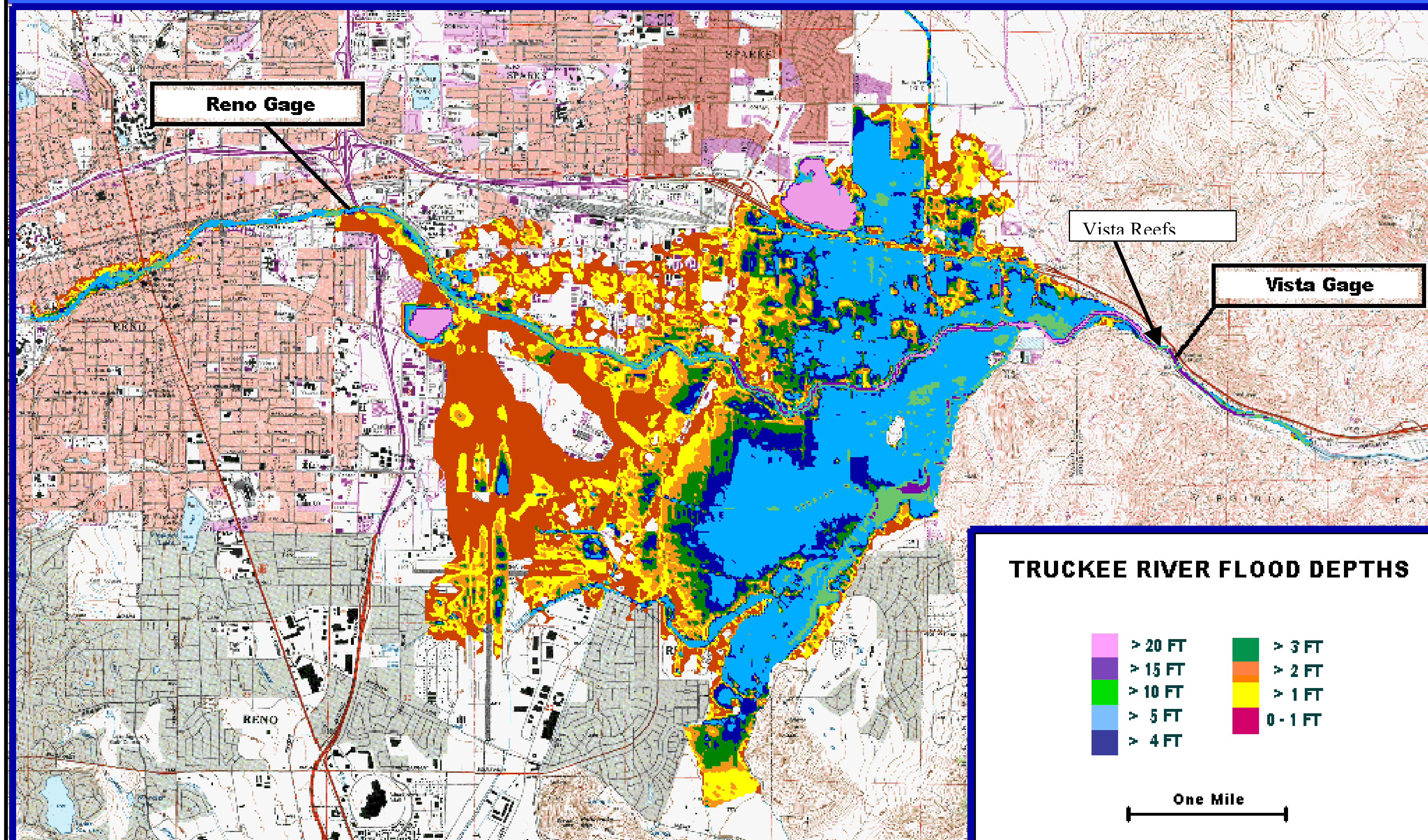
Conclusions: To reduce the uncertainty of the timing and volume of the local tributary runoff in the Truckee Meadows Reach, target peak flows for the hydraulic model were derived at Vista. Due to challenges in creating a conventional frequency curve, two methods, both based on the concept of dependence between the Reno and Vista gages, were used for calculating the Vista curve.

The original Vista and Reno unregulated 7-day curves, used to estimate local tributary runoff volume, crossed each other. By reducing the data set in both curves to the same water years and storm events, two new curves were derived that were parallel to each other.



PYRAMID LAKE
NIXON
WEBBER LAKE
INDEPENDENCE LAKE
STAMPEDE RES.
PROSSER CR. RES.
BOCA RES.
DONNER LAKE
TRUCKEE
FARAD
VERDI
LAWTON
RENO
SPARKS
VISTA
WADSWORTH
FERNLEY
DERBY DAM
MARTIS CR. LAKE
Mt. Rose
Huffaker Hills
WASHOE LAKE
LAKE TAHOE
TAHOE CITY
CARSON CITY
CALIFORNIA
NEVADA
SIERRA NEVADA MTNS
LEGEND
Drainage Boundary
U.S. Highway
State Highway
Interstate Highway
Railroad
County Boundary
Indian Reservation Boundary
Intermittent Stream
Perennial Stream
Reservoir or Lake
Ditch or Canal
SCALE
(Miles)

CHART 1



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Water Management Section, Sacramento District,
US Army Corps of Engineers

Chart 2

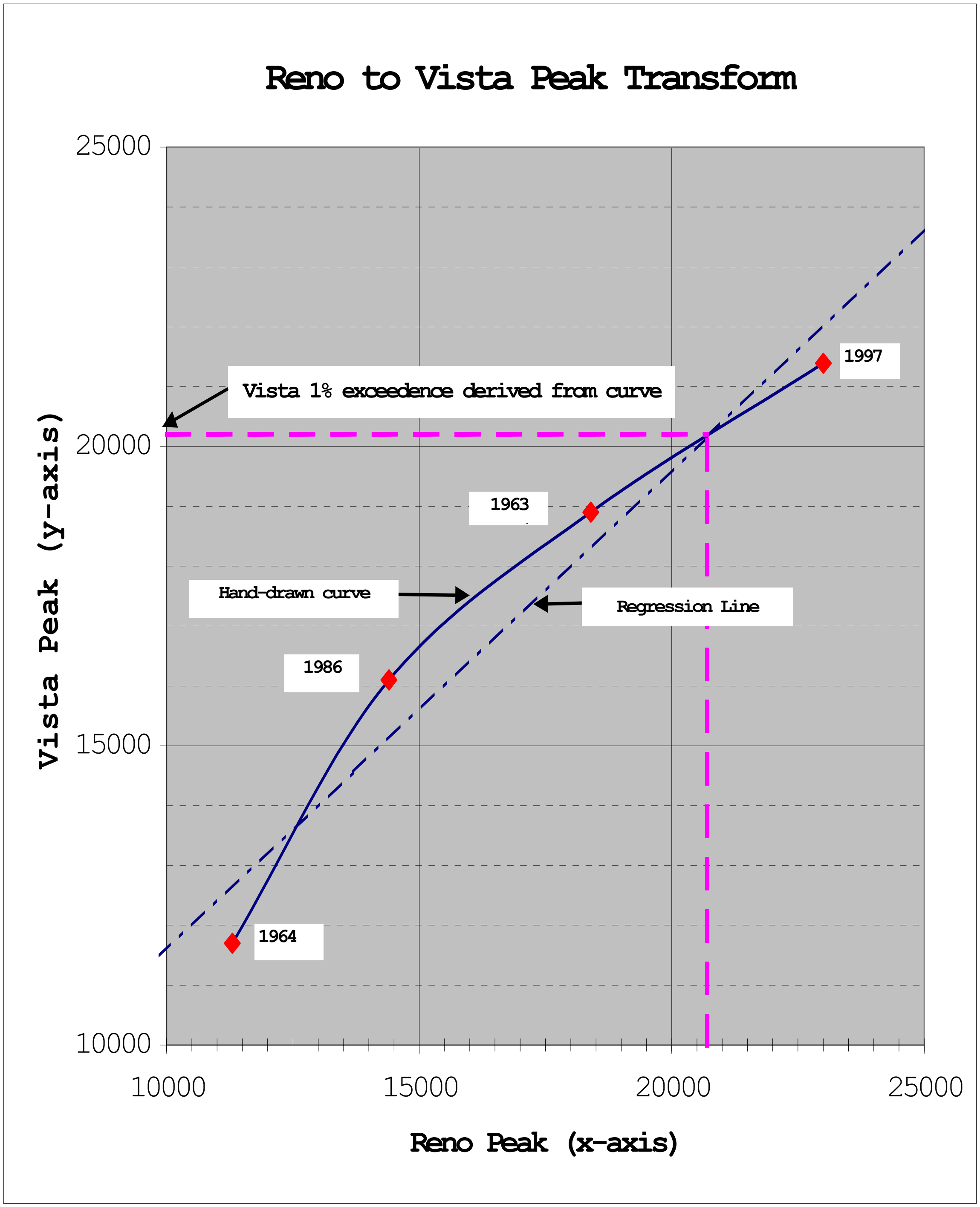

Reno to Vista Peak Transform
Vista Peak (y-axis)
25000
20000
15000
10000
10000
15000
20000
25000
Reno Peak (x-axis)
Vista 1% exceedence derived from curve
1997
1963
Hand-drawn curve
Regression Line
1986
1964

Chart 3

Synthetic Vista Frequency Curve

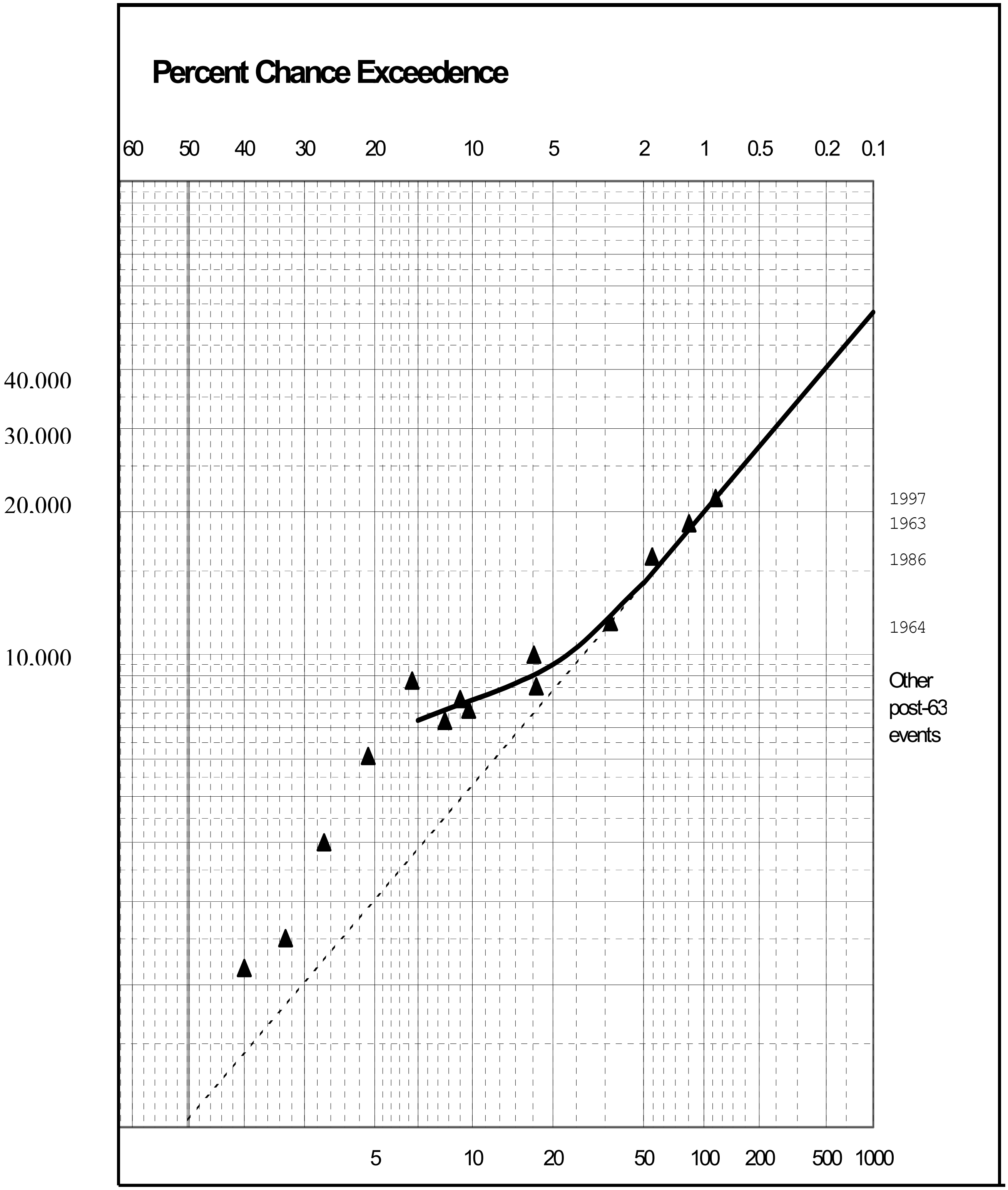


Chart 4

Comparison of Methods to Calculate Vista Peak Frequency

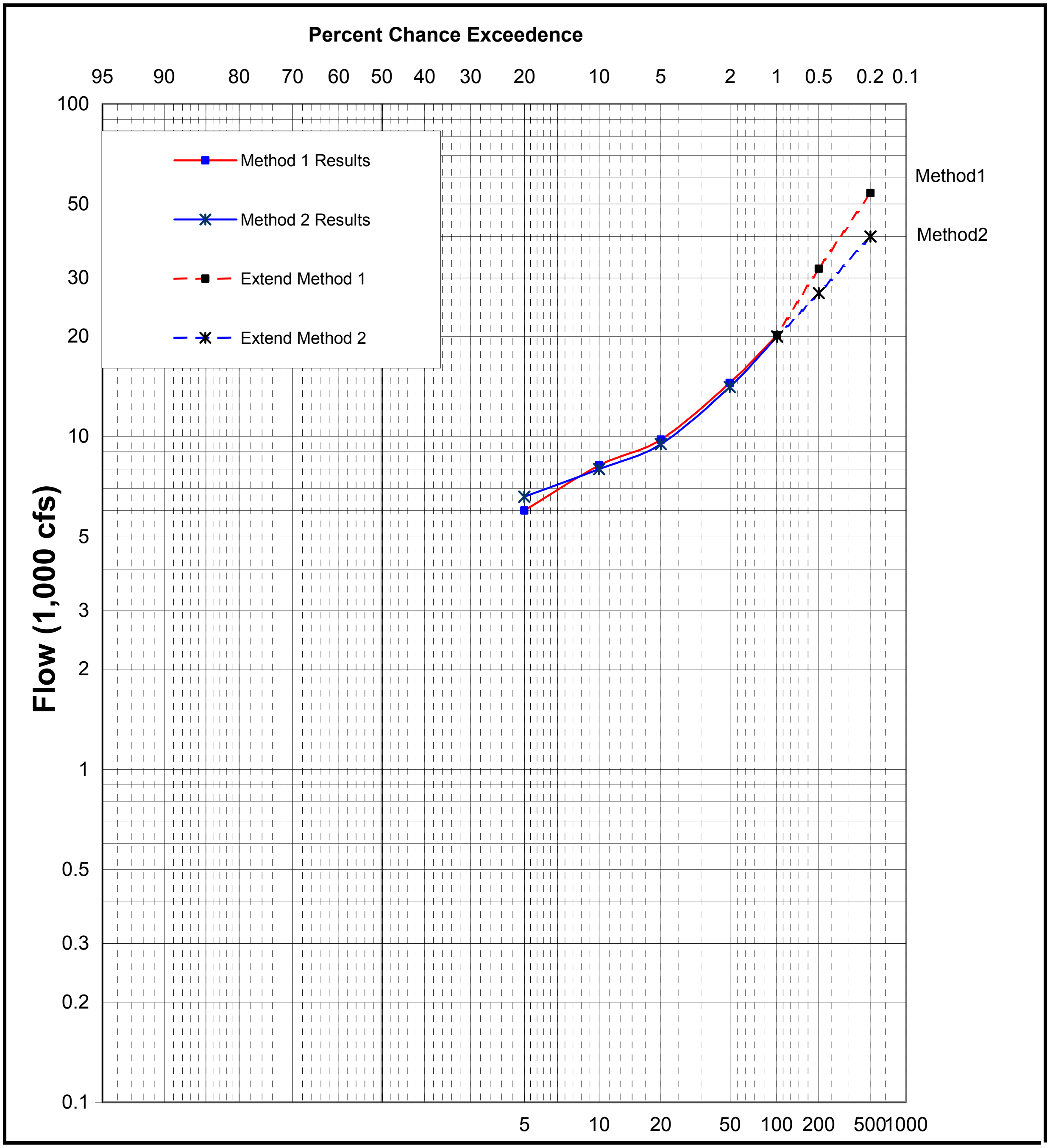
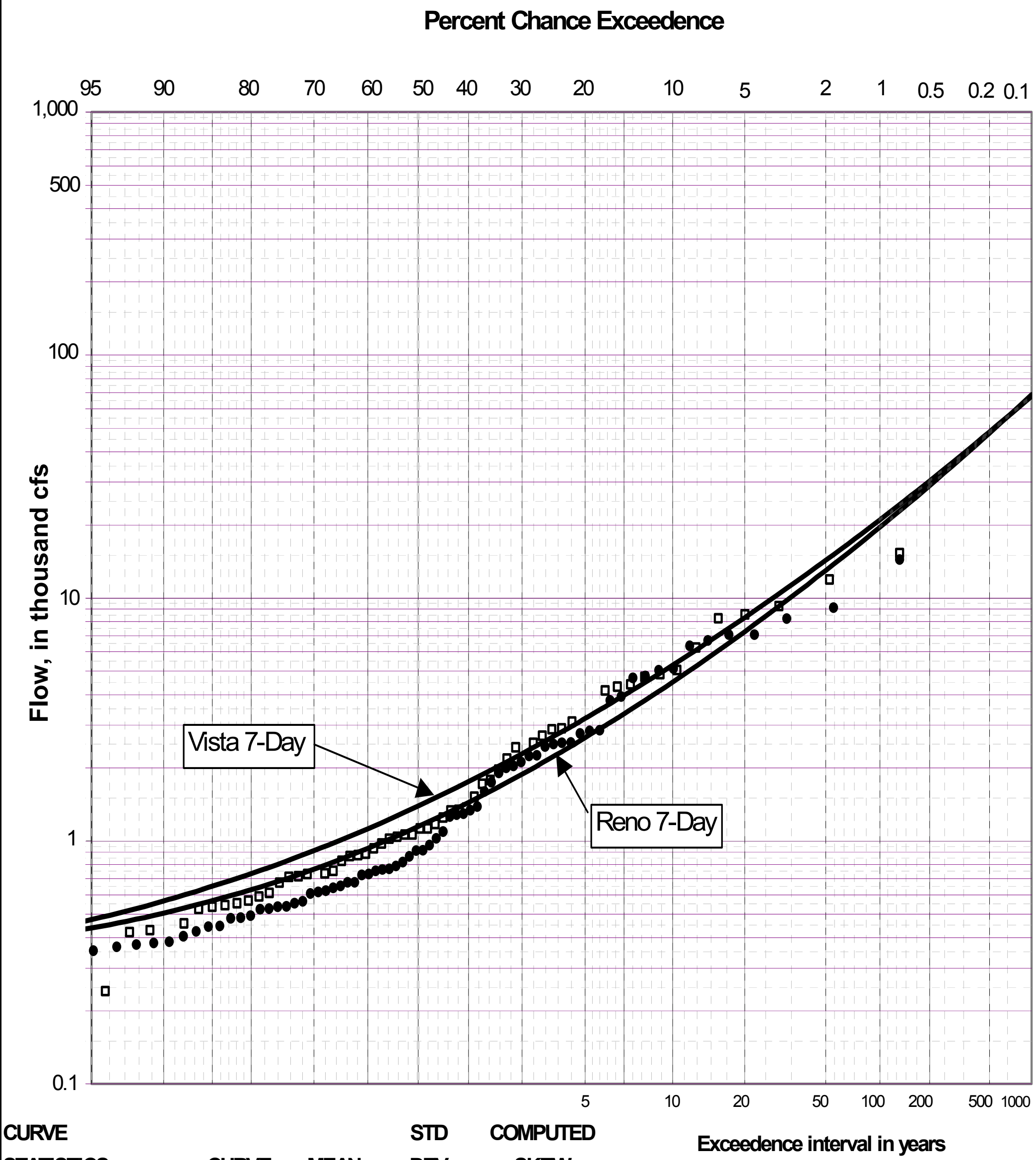


Chart 5

Original Reno and Vista Peak 7-Day
Unregulated Flow Frequency Curves



CURVE STATISTICS	CURVE	MEAN	STD DEV	COMPUTED SKEW
VISTA	7-DAY	3.095	0.458	0.40
RENO	7-DAY	2.973	0.492	0.40

Chart 6

New Reno and Vista Peak 7-Day Unregulated Curves
Using the Same Water Years and Storms

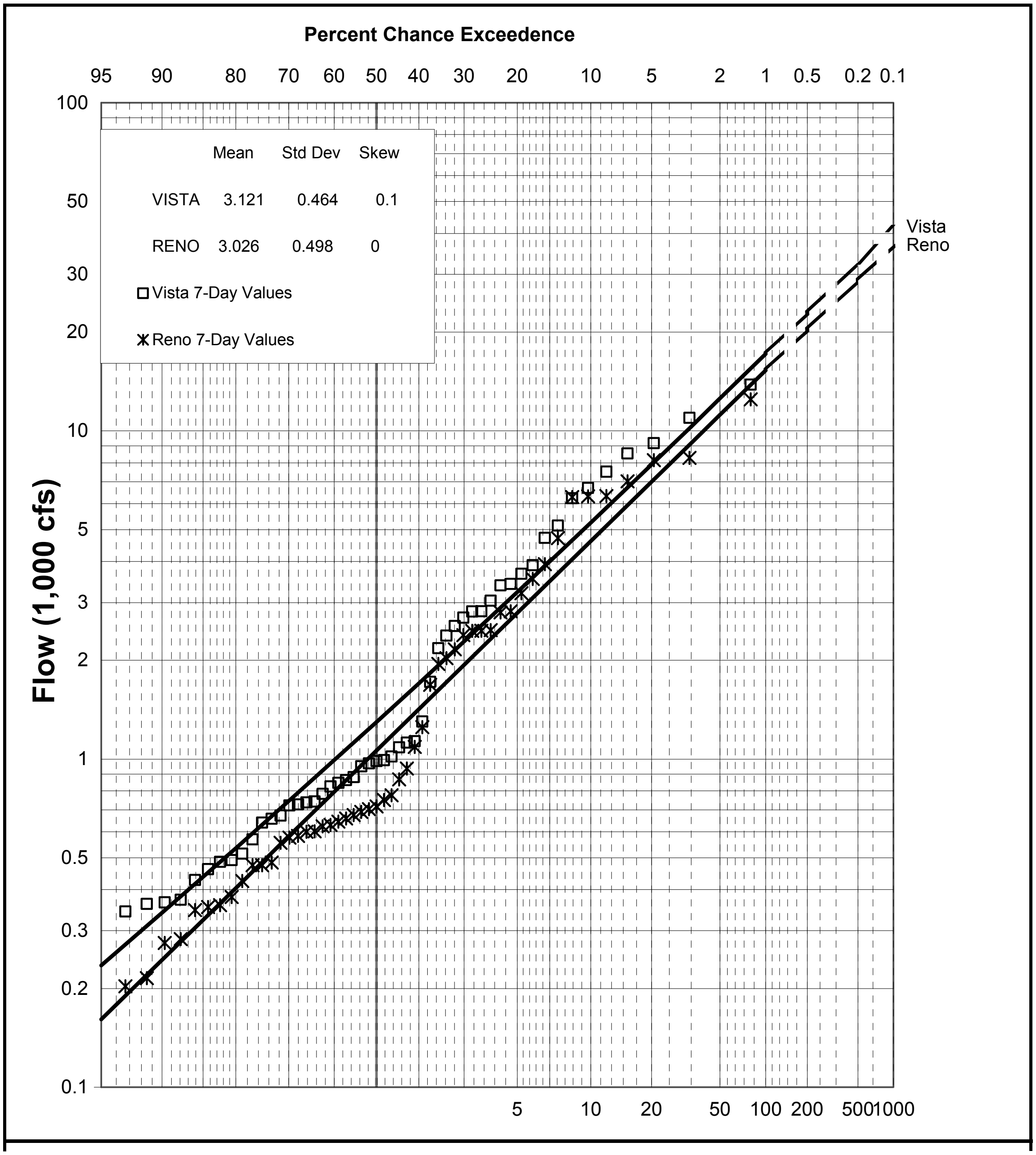


Chart 7